APPLICATIONS OF THE MOC3031 AND MOC3041 ZERO-CROSSING TRIAC DRIVERS

Prepared by
Doug Kervin

INTRODUCTION

Many new applications in the power control field have been made possible by Motorola's introduction in 1977 of the MOC3011 and MOC3021 optically isolated triac drivers. These six-pin, solid-state devices, with an input current of as little as 15 mA, can supply up to 100 mA drive current to switch triacs on either the 115 Vac or 230 Vac power line. Thus, high power ac loads can be controlled from low power circuitry, while an isolation voltage of 7.5 kV is maintained from input to output.

Now, increased flexibility in power control is possible with the addition of the MOC3031 and MOC3041 optically isolated, zero-crossing triac drivers. While retaining the many advantages of the MOC3011 and MOC3021, these new devices offer a unique zero-crossing feature, guaranteeing the triac driver will only 'switch on' between −25 V and +25 V. This insures lower generated noise and inrush currents and extends the life of incandescent lamp filaments. The circuitry necessary for zero-crossing is also responsible for improved device parameters, allowing the use of the MOC3031 and MOC3041 in a very wide range of applications.

Zero-crossing triac drivers are currently being used in electrically noisy industrial environments, where control signals may travel several hundred yards before reaching the MOC3031 or MOC3041 triac driver. This is due to the improved common-mode noise immunity of these devices. Their large static dv/dt rating eliminates the need for snubber networks and guarantees that the zero-crossing triac drivers cannot be unintentionally triggered 'on,' by ac line noise. This is particularly important when the triac driver is used to control industrial equipment where inadvertent operation may cause damage or injury.

DESCRIPTION

Construction

Each of the devices in the triac driver family consists of a gallium arsenide, infrared LED, optically exciting a silicon detector chip. The detector chip is designed to drive triacs on the 115 Vac power line, in the case of the MOC3011 and MOC3031 and triacs on the 230 Vac power line, in the case of the MOC3021 and MOC3041. The MOC3031 and MOC3041 detector chips also include the zero-crossing circuitry. This ensures that, with a continuous trigger current through the LED, the detector will not switch to the conducting state until the applied voltage passes through a point near zero. All of the triac drivers allow a low power exciting signal to drive a high power load, with almost complete isolation of the driving circuitry from the power line.

The zero-crossing triac drivers use the same coupler technology employed in Motorola's line of plastic couplers; refer to Figure 1. The combination of dual lead frame and epoxy undermold, makes possible a 7.5 kV isolation voltage between the input and output sides of the device. The detector chip is silicon nitride passivated and uses Motorola's annular ring to maintain stable breakdown parameters.

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Electrical Characteristics

The GaAs LED has a maximum forward voltage drop of 1.5 V at 30 mA and a reverse breakdown voltage of 3.0 V or more. The recommended LED current to trigger the detector (either the MOC3031 or MOC3041), is 15 mA. Two similar devices, the MOC3030 and MOC3040 have recommended LED currents of 30 mA to latch the output. The minimum LED pulse width capable of triggering the detector is typically 10 microseconds at both 15 mA (for the MOC3031 and MOC3041) and 30 mA (for the MOC3030 and MOC3040).

The MOC3031 detector has a minimum blocking voltage of 250 Vdc in either direction in the 'off' state, whereas the minimum blocking voltage of the MOC3041 is 400 Vdc. Once triggered 'on,' either detector will pass 100 mA with less than 3.0 V drop across the device. Both will remain in this conducting state until the current drops below the holding current (typically 100 μA for the MOC3031, 200 μA for the MOC3041), at which time the detector returns to the non-conducting state.

It may also be possible to inadvertently trigger the detector into the 'on' state by exceeding the forward blocking voltage or by voltage ramps across the detector exceeding the static dv/dt rating. These voltage ramps usually appear as disturbances on the ac power line. However, since the typical static dv/dt rating of the zero-crossing triac driver is in excess of 1000 V/microsecond at 100°C, ac line noise poses little or no problem for these devices. As a result, the need for snubber networks on the triac drivers, to reduce the speed of voltage ramps, is eliminated. Figure 2 shows the static dv/dt test circuit.

Once the triac controlled by a triac driver is switched to the conducting state, very little voltage appears across MT1 and MT2, the main terminals of the triac; refer to Figure 3. Since there is also a small voltage drop from the gate to T2, the total voltage across the triac driver terminals T1 and T2 is very small — typically less than 2.0 V. Thus, the detector of the triac driver will conduct very little current and will, for practical purposes, be 'off.' This condition has very important implications when a triac driver and triac are being used to control an inductive load.

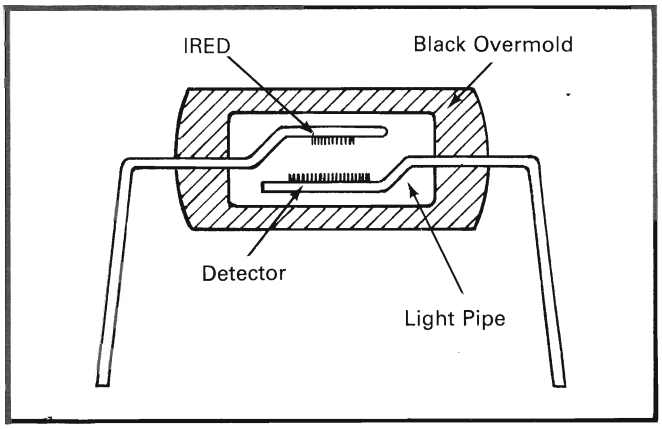
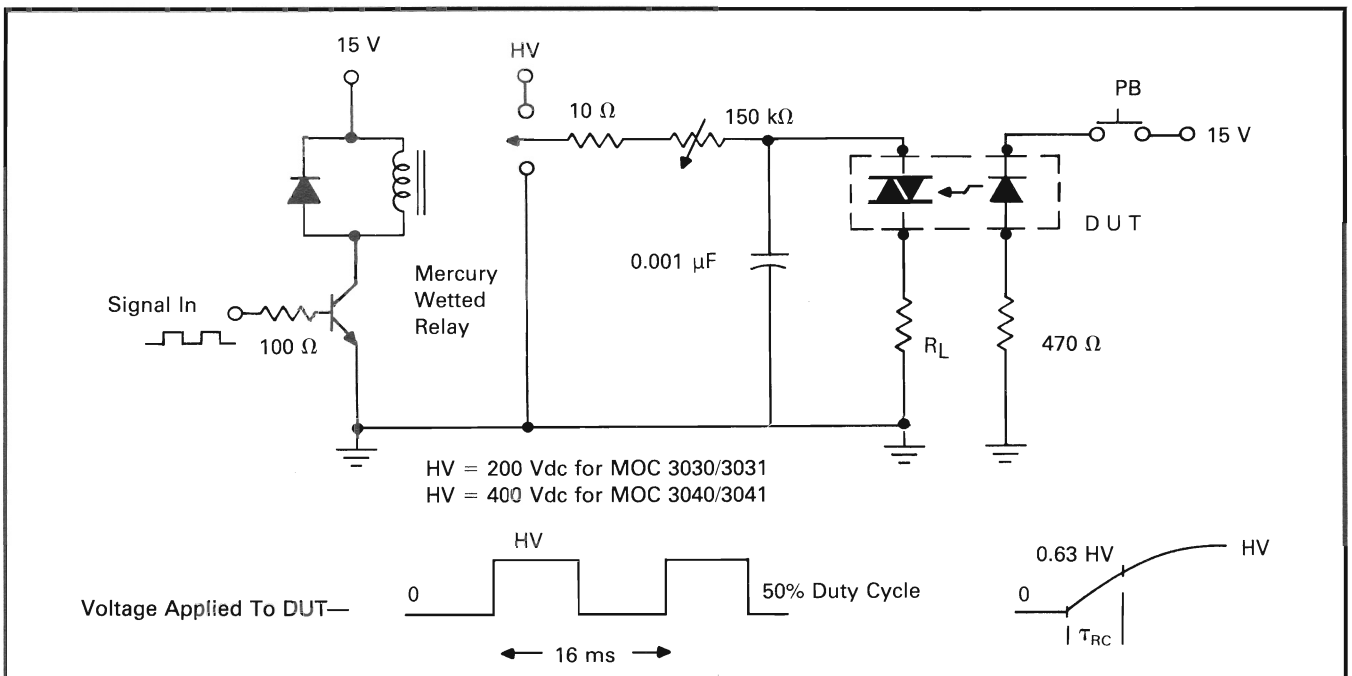


FIGURE 1 — Motorola Double-Molded Coupler Package



TEST PROCEDURE —

Turn the D.U.T. on, while applying sufficient dv/dt to ensure that it remains on, even after the trigger current is removed. Then decrease dv/dt until the D.U.T. turns off. Measure τ_{RC}, the time it takes to rise to 0.63 HV, and divide 0.63 HV by τ_{RC} to get dv/dt.

FIGURE 2 — Static dv/dt Test Circuit

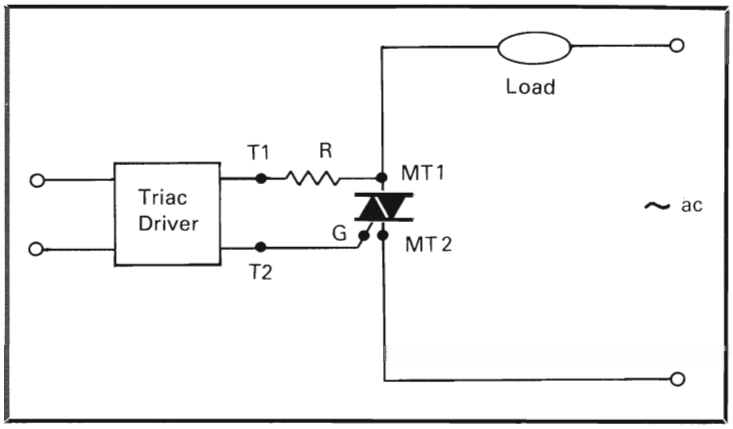


FIGURE 3 — Typical AC Power Line Control Circuit

Commutating dv/dt, a phenomena associated with inductive loads, presents a problem for both triacs and zero-crossing triac drivers. In the steady state, voltage and current are 90 degrees out of phase for an inductive load. Therefore, when a triac attempts to turn 'off' at zero current, the applied voltage is high. This sudden rise in voltage will trigger the triac back 'on' if it exceeds the commutating dv/dt of the triac, since it has been on; or, the static dv/dt of the triac driver, since it has been basically off. Because the static dv/dt of the zero-crossing triac driver is so large, the commutating dv/dt of the triac will be the limiting factor. Therefore, commutating dv/dt only becomes a limiting factor when the zero-crossing triac drivers are being used in direct drive applications. Figure 4A shows commutating dv/dt versus ambient temperature and load resistance for the zero-crossing triac drivers.

Another important parameter associated with the zero-crossing triac drivers, is common-mode dv/dt. A large common-mode dv/dt rating is essential when using these devices in a noisy environment, due to the possibility of triggering the triac drivers 'on' with a common-mode spike on either the LED or detector. The test circuit used to measure this quantity is shown in Figure 5. Typical values exceed 5000 V/μs at 100°C. This value is attained through the inhibiting action of the internal circuitry of the zero-crossing triac drivers.

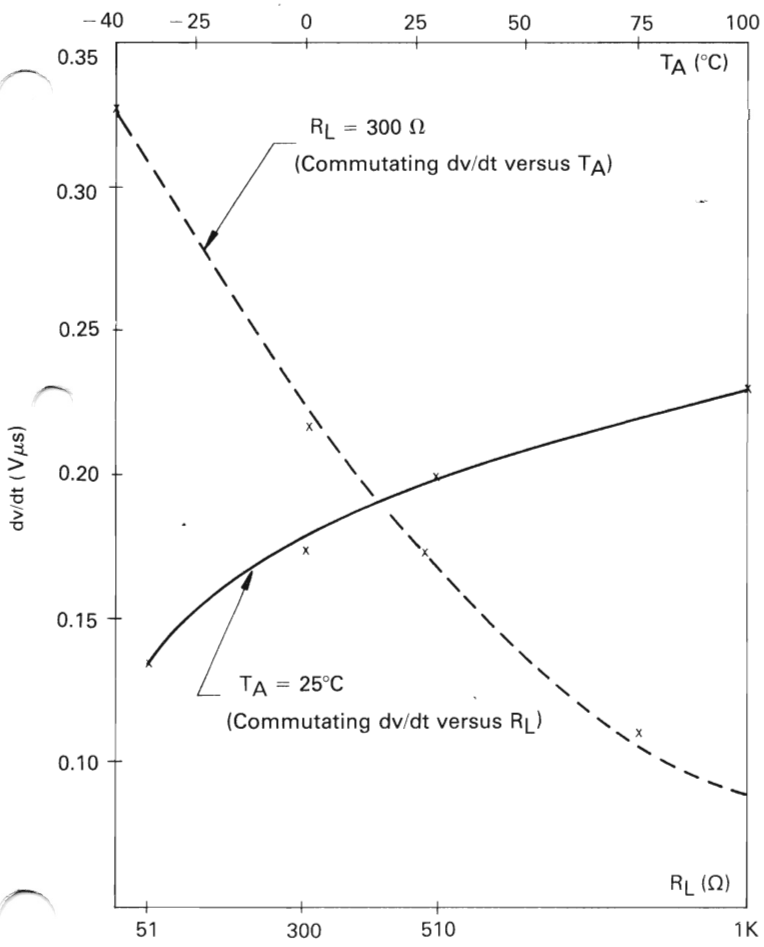
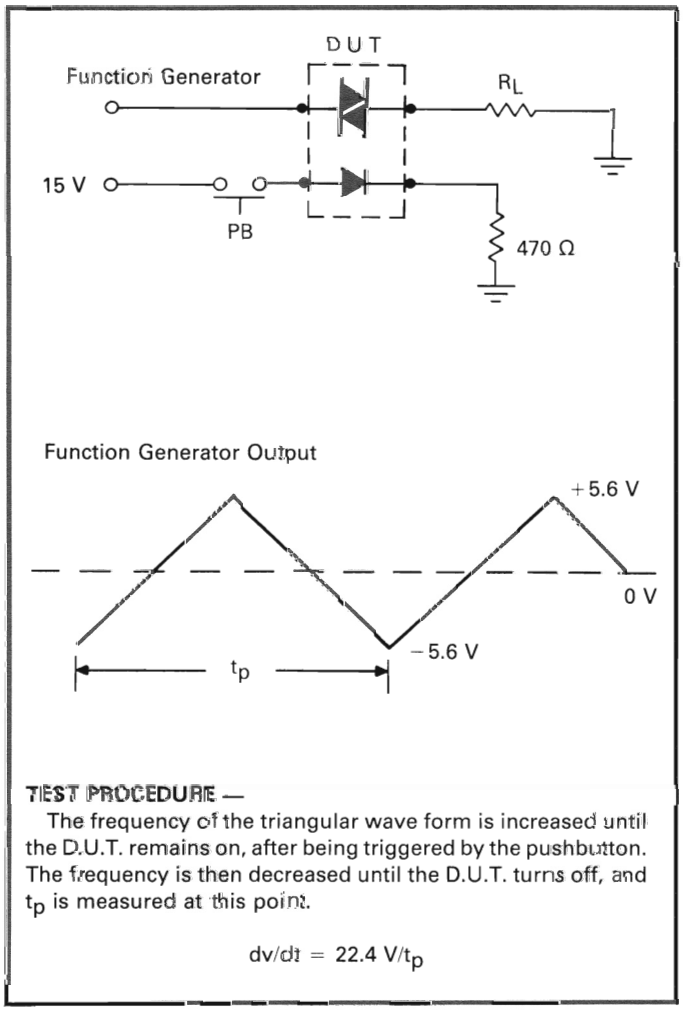


FIGURE 4A — Commutating dv/dt versus Ambient Temperature and Load Resistance

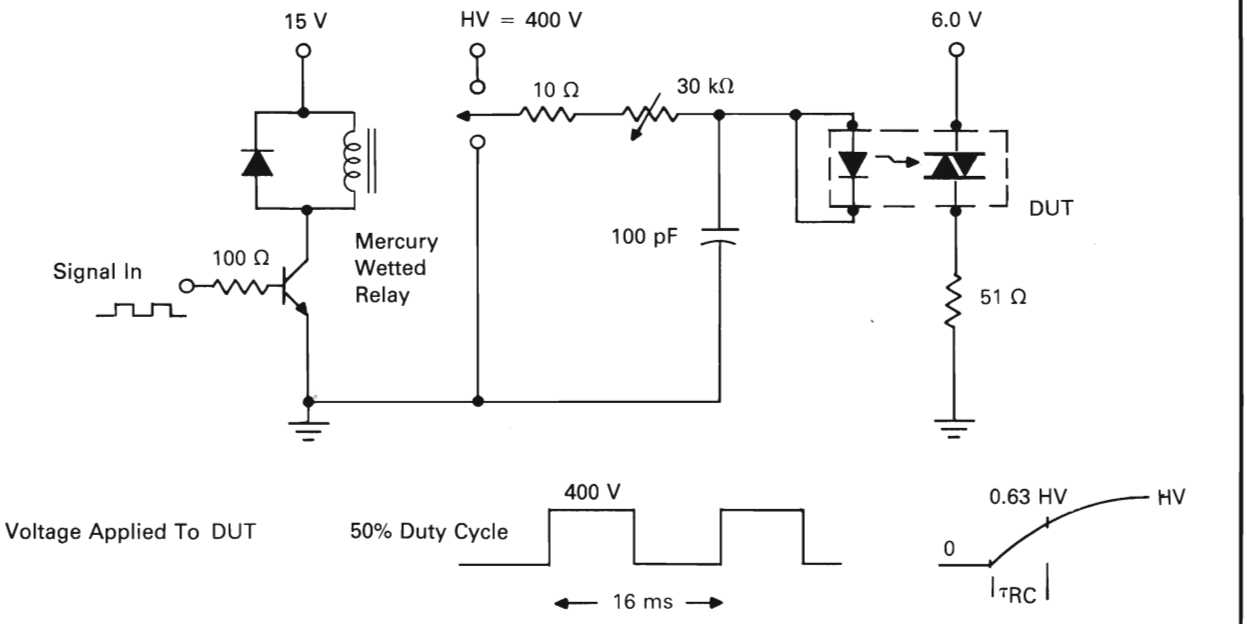


TEST PROCEDURE —

The frequency of the triangular wave form is increased until the D.U.T. remains on, after being triggered by the pushbutton. The frequency is then decreased until the D.U.T. turns off, and t_p is measured at this point.

$$dv/dt = 22.4\ V/t_p$$

FIGURE 4B — Test Circuit for Commutating dv/dt



TEST PROCEDURE —

Apply sufficient common-mode dv/dt to trigger the D.U.T. Measure τ_{RC}, the time it takes to rise to 0.63 HV and divide 0.63 HV by τ_{RC} to get dv/dt.

FIGURE 5 — Common-Mode dv/dt Test Circuit

Zero-Crossing Circuitry

Several of the benefits made possible by the zero-crossing circuitry have already been discussed. The large common-mode dv/dt makes these devices insensitive to common-mode EMI. In the same manner, the typical static dv/dt rating of 1000V/microsecond at 100°C virtually eliminates the possibility of the zero-crossing triac drivers being unintentionally triggered on by ac line noise. This also eliminates the need for snubber networks on the triac drivers, along with their associated component cost and printed circuit board space.

In addition to the improvement in device parameters caused by the zero-crossing circuitry, the basic concept of switching the load 'on' only near zero voltage has many benefits. These include lower generated noise and inrush currents, along with extended filament life in the case of incandescent lamps.

There has been some controversy as to whether a peak-crossing triac driver might be more appropriate, rather than a zero-crossing triac driver, when controlling inductive loads. This discussion arises because the voltage and current are 90 degrees out of phase in an inductive load. Thus, at first glance, it would seem logical to switch an inductive load 'on' at peak voltage to minimize the inrush current. However, upon closer inspection, the flaw in this argument can be seen. Voltage and current are only 90 degrees out of phase in an inductive load in the steady state. When switching an inductive load 'on,' an initial transient response is also present. This transient response must be added to the steady state response to fully characterize current flow in an inductive load. To illustrate this behavior, analyze the circuit of Figure 6, which can be used to model the response of an inductive load to the sudden application of a sinusoidal voltage.

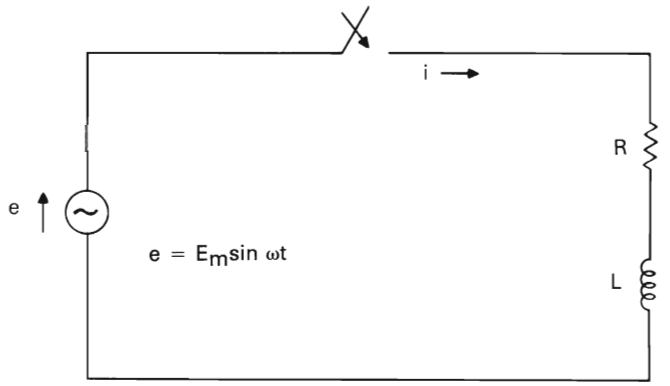


FIGURE 6 — Circuit Model for Inductive Load Response

The switch is closed at t = 0. Thus, the applied voltage will be zero at this instant, analogous to the use of a zero-crossing triac driver. A small series resistance (R) has been included, since all inductors have some finite resistance.

The governing differential equation is

$$e = iR + L\frac{di}{dt} \qquad (1)$$

with the initial condition $i(0-) = i(0+) = 0$, due to the inductor and no current flowing in the circuit with the switch open.

The total solution to this differential equation is the sum of a transient and steady state response

$$i_{TOT} = i_{TRAN} + i_{SS} \quad (2)$$

where

$$i_{TRAN} = A_1 e^{-Rt/L} \quad (3)$$

and

$$i_{SS} = A_2 \sin \omega t + A_3 \cos \omega t \quad (4)$$

Substituting these solutions into the governing differential equation and satisfying the initial condition gives

$$i_{TOT} = \overbrace{\frac{E_m L\omega}{R^2 + L^2\omega^2} e^{-Rt/L}}^{i_{TRAN}} + \overbrace{\frac{E_m R}{R^2+L^2\omega^2} \sin \omega t - \frac{E_m L\omega}{R^2+L^2\omega^2} \cos \omega t}^{i_{SS}} \quad (5)$$

This solution also gives insight into another important parameter associated with triacs — the di/dt rating. If the maximum di/dt rating of a triac is exceeded, the triac characteristics can be adversely affected or the triac permanently damaged. In the case of the zero-crossing triac driver, the di/dt applied to the triac is easily calculated from the previous solution.

$$\frac{di_{TOT}}{dt} = \frac{-R}{L} \frac{E_m L\omega}{R^2+L^2\omega^2} e^{-Rt/L} + \frac{E_m R\omega}{R^2+L^2\omega^2} \cos \omega t + \frac{E_m L\omega^2}{R^2+L^2\omega^2} \sin \omega t \quad (6)$$

$$\left.\frac{di_{TOT}}{dt}\right|_{t=0} = 0$$

Thus, there is little possibility of damage to the triac when using a zero-crossing triac driver. If a peak-crossing triac driver were used, the voltage source shown in Figure 6 would become $e = E_m \cos \omega t$ to model the peak voltage impressed across the load at $t = 0$. The initial condition of $i(0-) = i(0+) = 0$ remains the same and the solution becomes

$$i_{TOT} = \overbrace{\frac{-E_m R}{R^2+L^2\omega^2} e^{-Rt/L}}^{i_{TRAN}} + \overbrace{\frac{E_m L\omega}{R^2+L^2\omega^2} \sin \omega t + \frac{E_m R}{R^2+L^2\omega^2} \cos \omega t}^{i_{SS}} \quad (7)$$

With a peak-crossing triac driver

$$\frac{di_{TOT}}{dt} = \frac{R}{L} \frac{E_m R}{R^2+L^2\omega^2} e^{-Rt/L} + \frac{E_m L\omega^2}{R^2+L^2\omega^2} \cos \omega t - \frac{E_m R\omega}{R^2+L^2\omega^2} \sin \omega t \quad (8)$$

$$\left.\frac{di_{TOT}}{dt}\right|_{t=0} = \frac{E_m}{R^2+L^2\omega^2} \left[\frac{R^2}{L} + L\omega^2\right] = \frac{E_m}{L} \quad (9)$$

This value can become very large depending upon the peak applied voltage and inductance of the load. If it exceeds the maximum di/dt rating of the triac, serious damage can result.

It is easy to conclude that, when controlling inductive loads using a triac driver and triac, a zero-crossing triac driver is a far more desirable device than a peak-crossing triac driver.

APPLICATIONS

High-Wattage Incandescent Lamps

Many high-wattage incandescent lamps suffer from shortened lifetimes when switched on at ac line voltages other than zero. This is due to a large inrush current destroying the filament. A simple solution to this problem is the use of the MOC3041, as shown in Figure 7. The MOC3041 may be controlled from a switch or some form of digital logic.

The minimum value of R is determined by the maximum surge current rating of the MOC3041 (I_{TSM}):

$$R(min) = V_{in}(pk)/I_{TSM} = V_{in}(pk)/1.2A \quad (10)$$

On the 230 Vac Line:

$$R(min) = 340\ V/1.2\ A = 283\ ohms \quad (11)$$

In reality, this would be a 300 ohm resistor.

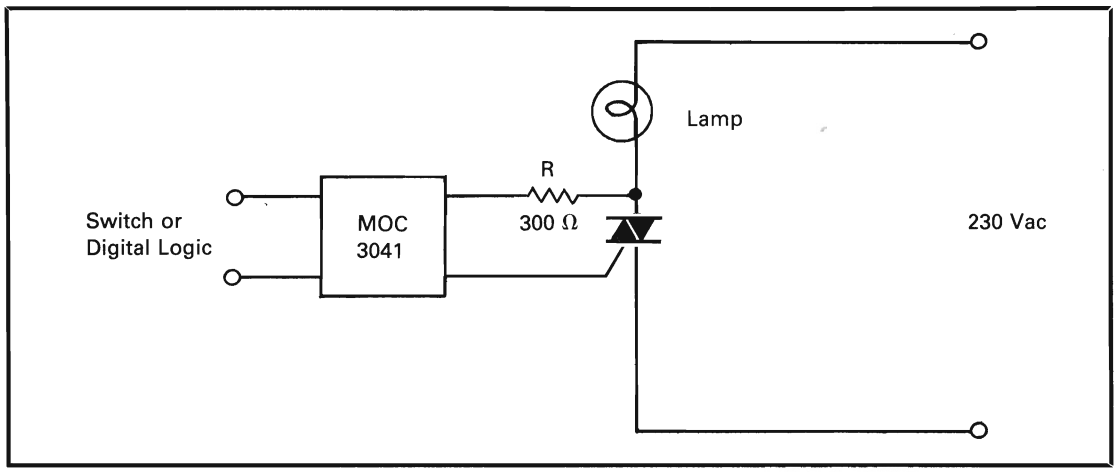


FIGURE 7 — High-Wattage Lamp Control

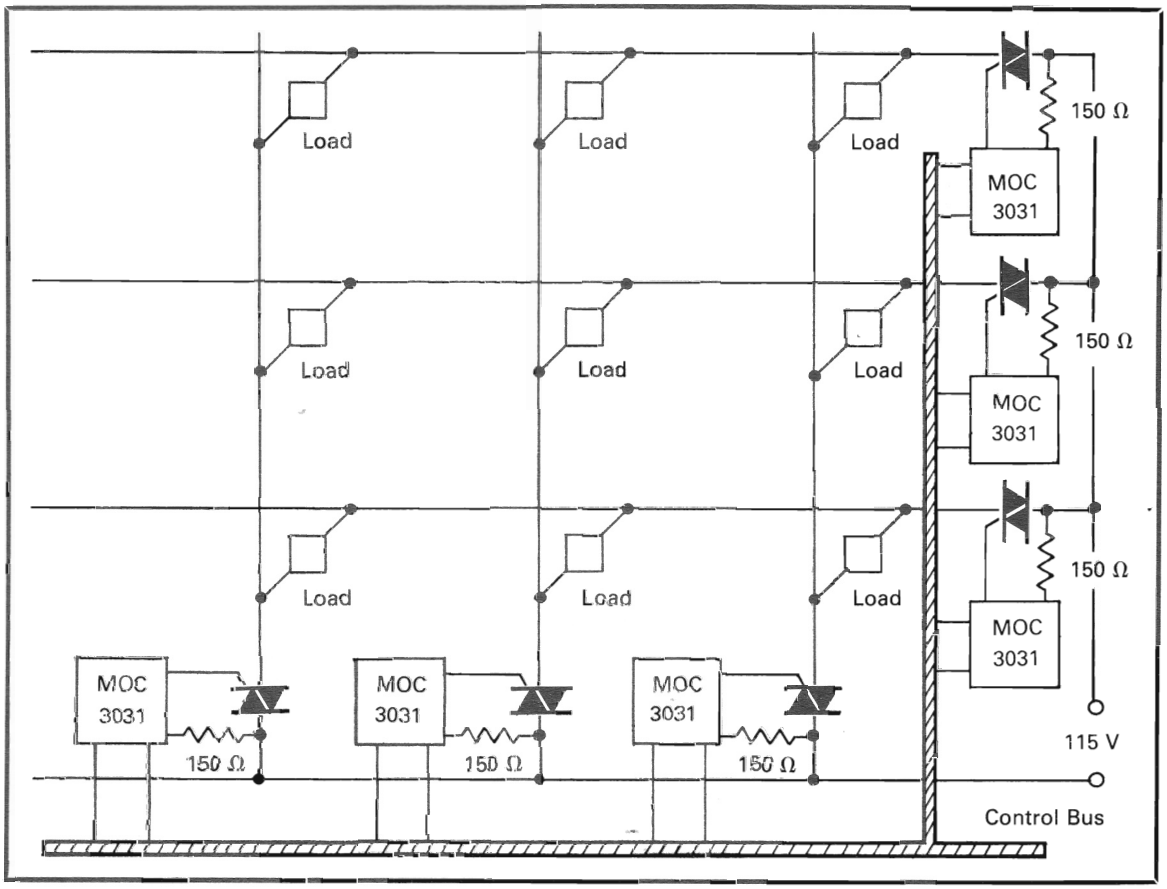


FIGURE 8 — Matrix Switching

Matrix Switching

Matrix, or point-to-point switching, represents a method of controlling many loads using a minimum number of components. On the 115 Vac line, the MOC3031 is ideal for this application; refer to Figure 8. The large static dv/dt rating of the MOC3031 prevents unwanted loads from being triggered 'on.' This might occur, in the case of non-zero crossing triac drivers, when a triac driver on a vertical line was subjected to a large voltage ramp due to a triac on a horizontal line being switched on. Since non-zero crossing triac drivers have lower static dv/dt ratings, this ramp would be sufficiently large to trigger the device 'on.'

R is determined as before:

$$R(\text{min}) = V_{in}(pk)/I_{TSM}$$
$$= 170\ V/1.2\ A = 150\ \text{ohms} \quad (12)$$

Power Relays

The use of high-power relays to control the application of ac power to various loads is a very widespread practice. Their low contact resistance causes very little power loss

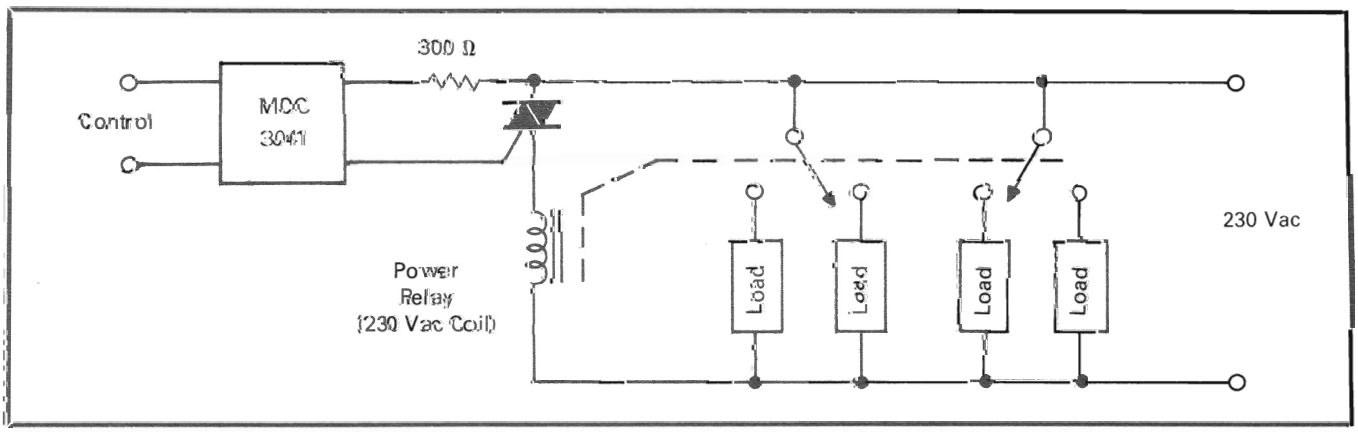


FIGURE 9 — Power Relay Control

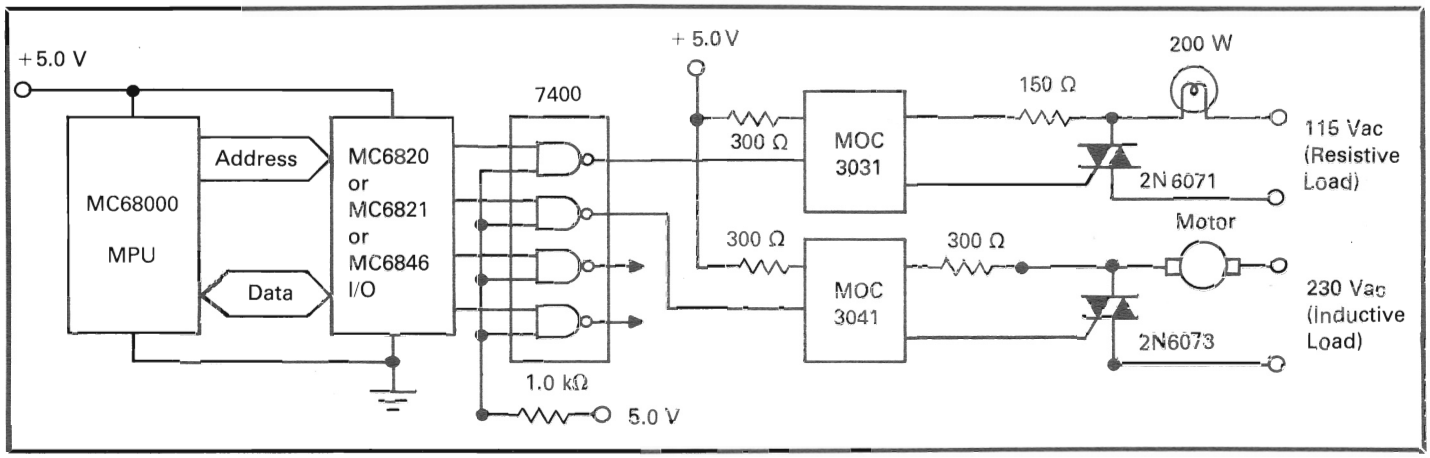


FIGURE 10 — M68000 Microcomputer Interface

and many options in power control are possible due to their multipole-multithrow capability. The MOC3041 is well suited to the use of power relays on the 230 Vac line; refer to Figure 9. The large static dv/dt of this device makes a snubber network unnecessary, thus reducing component count and the amount of printed circuit board space required. A non-zero crossing triac driver (MOC3021) could be used in this application, but its lower static dv/dt rating would necessitate a snubber network.

Microcomputer Interface

The output of most microcomputer input/output (I/O) ports is a TTL signal capable of driving several TTL gates. This is insufficient to drive a zero-crossing triac driver. In addition, it cannot be used to drive an SCR or triac directly, because computer common is not usually referenced to one side of the ac supply. However, standard 7400 NAND gates can be used as buffers to accept the output of the I/O port and in turn, drive the MOC3031 and/or MOC3041; refer to Figure 10.

The zero-crossing feature of these devices extends the life of incandescent lamps, reduces inrush currents and minimizes EMI generated by load switching.

AC Motors

The large static dv/dt rating of the zero-crossing triac drivers make them ideal when controlling ac motors. Figure 11 shows a circuit for a reversing induction motor using the MOC3041. The higher voltage MOC3041 is required, even on the 115 Vac line, due to the mutual and self-inductance of each of the motor windings, which may cause a voltage much higher than 115 Vac to appear across the winding which is not conducting current.

The optional triac snubber network may be necessary, depending upon the static dv/dt rating of the triac and the voltage ramp generated by the motor when changing its direction of rotation.

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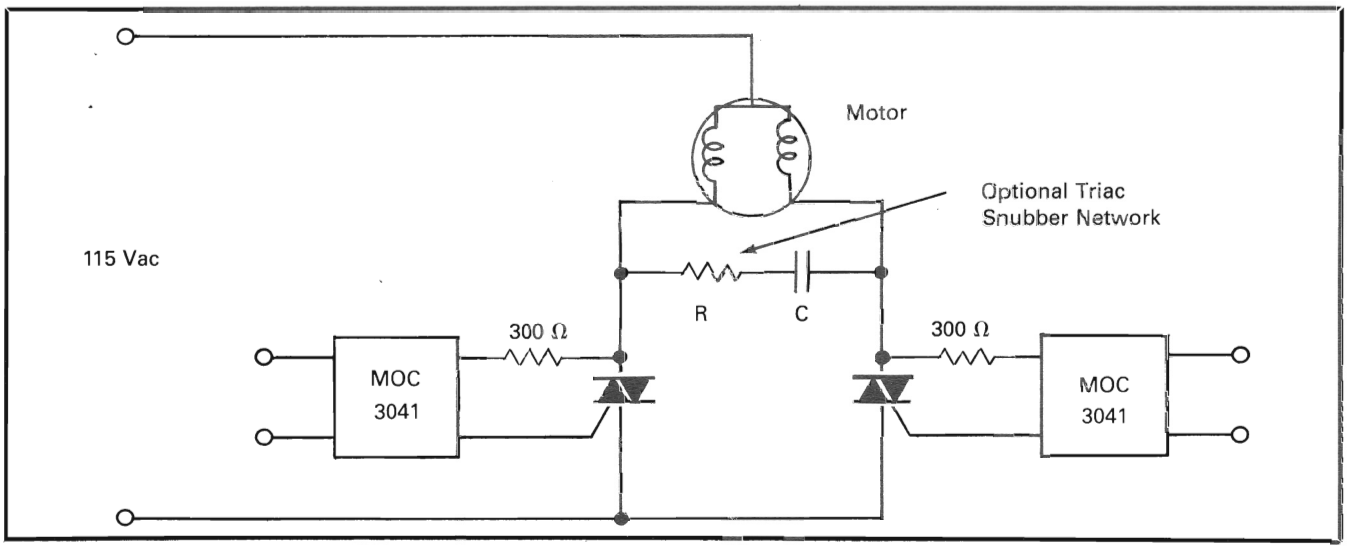

FIGURE 11 — Reversing Motor Circuit

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